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ABSTRACT

Beginning teachers of scientific technical writing often have little background knowledge in the sciences; thus, they may encounter difficulty in dealing with technical reports. To achieve clear explanations of the effects of scientific experiments, scientific writers need to know the following general principles: (1) the function of all the sciences is to predict, but the philosophers of science rank the various sciences in a hierarchical order of predictive ability from physics (highest in predictive ability) through chemistry and biology to psychology (lowest in predictive ability); (2) the esoteric terminology of each science may be clarified by asking for operational definitions of terms and concepts; (3) experimental tests of prediction follow a common, simple, logical plan; and (4) the mathematical proofs of experimental results can be made clear if the aim, rather than the method, of the mathematics is discussed. When scientific writers and their teachers understand these principles, they can help to make scientific writing not only clear but interesting. (An outline of experimental investigation is attached with two illustrations of its application.) (RL)

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THE ORGANIZATION OF REPORTS OF SCIENTIFIC EXPERIMENTS

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Abstract

Teachers of technical writing are usually trained in English composition and literature and have normally taken few courses in science, engineering, or mathematics. It may be of some help to them to understand: (1) that the function of all the sciences is to predict, but that philosophers of science rank the various sciences in a hierarchal order of predictive ability; (2) that the esoteric terminology of each science may be clarified by asking for operational definitions of terms and concepts; (3) that experimental tests of prediction follow a common, simple, logical plan which is illustrated in this paper in outline form; and finally (4) the mathematical proofs of experimental results can be made clear if the aim, rather than the method, of the mathematics is discussed.

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THE ORGANIZATION OF REPORTS OF SCIENTIFIC EXPERIMENTS

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Teachers of technical writing are usually drawn from the ranks of people trained in English composition, literature, or, as in my case, Speech. Programs in English or Speech normally require few courses in science or in engineering and technology which involve the practical applications of science. For this reason beginning teachers of technical writing may have some difficulty at first in dealing with reports in which the subject matter is drawn from those fields. Let me illustrate.

On the cover of Scientific American for October 1977 you will see what appears to be an aerial photograph of the city of Flagstaff, Arizona. However, it is not an aerial photograph. It is a side-looking radar image taken from an airplane flying at 40,000 feet 25 miles east of Flagstaff. The radar pulses sent from the plane reflected from the surface of the ground and were received in the plane. There they were displayed on an a cathode-ray tube and recorded on photographic film making a radar hologram.

In 1971 Dr. Dennis Gabor won the Nobel Prize for developing the theory of holography, even though he produced no holograms himself. The practical development of holography was done by Professor Emmett Leith of our Electrical and Computer Engineering Department. He created the side-looking radar hologram technique in 1960 while working at the Radar Laboratories and everyone was delighted with the results. However, they could not understand how he managed to produce these interesting pictures and Emmett couldn't figure out how to explain it to them. So I was hired to see if I could write up an explanation that people could understand. I eventually succeeded, but I will let you read the article in that October 1977 Scientific American if you would like to understand the process. (Reference 3)

The problem in science writing is to explain how effects similar to this are created. Since many of you will be dealing with students from a variety of scientific fields, not merely electrical engineering, let me start off with some of the things that

all fields of science have in common.

James B. Conant, former president of Harvard University and a renown chemist, points out in his book, Modern Science and Modern Man, that the function of science is to predict--to predict what will happen under certain prescribed circumstances (Reference 2). That is the general aim of all sciences, but some sciences are better at predicting than others. So there is no single Science, in capital letters. There are the sciences--plural.

The differences between the various sciences has been of great interest to philosophers. And most philosophers seem to agree that the various sciences can be arranged in a hierarchy depending upon their ability to predict, and they all seem to agree on the order of this hierarchy. Physics is always considered the most developed science, the one best able to predict. Dr. Gabor's prediction that holography could be developed, even though he had not been able to construct a hologram, may serve to illustrate. Albert Einstein's prediction that energy is equal to mass multiplied by the square of the velocity of light may serve as another illustration.

Chemistry is usually considered the second science. It is not quite so able to predict as physics, although it is rapidly approaching physics in this ability. Biology follows chemistry. There are a good many things that biology cannot predict, or can only predict within some statistical probability. For example, people who are over-weight, who eat lots of carbohydrates, and who smoke are generally more subject to heart attacks than other people. But this rule does not seem to apply to a group of families of Italian extraction living near Philadelphia. Most of them are fat, eat lots of pasta, and smoke, but seem to be immune to heart attacks. Something about the Italian family life style seems to be beneficial, but what it is, no one seems to know.

Psychology follows biology and has even more touble predicting. For example, can you make a color picture from black and white film? Yes, you can, as Dr. Edwin Land of Polaroid Camera fame found out by accident. Make two black and white slides of the same color scene, one with a red filter over the camera lens, the other with green filter over the lens. Project both slides at the

same time so that they overlap on the screen, use the red filter on the projector with the slide shot through the red filter, but nothing on the other projector with the green shot slide. There you are--a color picture on the screen! Why do you see a color picture? No one really knows, but you can see one of Dr. Land's color pictures on the cover of Scientific American (Reference 4).

All sorts of reasons have been advanced for these differences between the sciences. Simplicity is one. Physics is simpler than chemistry because it omits chemical reactions. Chemistry is simpler than biology because it omits living organisms. Biology is simpler than psychology because it omits thinking organisms. And so forth.

Or ego involvement is another explanation. No one feels much sympathy for an atom, so it is all right to smash one. It won't scream for help. But people are awfully fond of puppy dogs and it makes most of them feel queasy to learn that surgeons sometimes practice their surgical techniques on dogs before trying them out on people.

But Anatol Rapoport argues that the hierarchy of the sciences is largely a matter of semantics; that is, the ability to define precisely what we are talking about. Physics is the best developed science because it starts with sharply defined, quantitative--that is, measurable, rather than intuitive--variables or phenomena. It may well be easier to find unchanging phenomena in physics than in biology. After all, living things grow, and thus change with time, while many physical phenomena stay the same and are thus easier to specify precisely. And you often can't take a living organism apart to see what makes it work without killing it, thus destroying the very thing you are trying to find out. (Reference 5)

When you first start teaching technical writing I suspect that one of the things that will bother you most is the jargon that scientists and engineers use, the terms they use to define things. Sanitary engineers will talk about "B.O.D.," Mechanical Engineers will talk about "Reynolds number," Biologists will talk about "myocardial perfusion," Psychologists will talk about "critical flicker fusion."

It sounds scary at first, but there is a very simple way of getting them to make these terms clear to almost anyone. The trick

is to force them to define these terms operationally.

This is, to my mind, one of the important rhetorical devices of science writing. The thing to remember is that Scientists know by measuring; or, as the philosopher Hannah Arendt put it, scientists know through process. To understand what a scientist means by a term, ask him how he measures it.

Take "B.O.D." for example. The sanitary engineer may tell you that it is a measure of the amount of pollution in a body of water and that "B.O.D." stands for biochemical oxygen demand. The term probably still means very little to most people. But now watch how it measures it. He takes several samples of water he thinks may be polluted, measures the amount of oxygen dissolved in one sample by adding chemical reagents to it, adds some coliform bacteria (the bacteria that live in our intestines) to the other samples, seals these sample bottles, and waits. At the end of several days he uncaps these sample bottles and measures the amount of oxygen still dissolved in them. The smaller the amount of oxygen, the more the coliform bacteria have used up because they had plenty of stuff to eat in those water samples.

Operational definitions are discussed in a very interesting book that I would heartily recommend to teachers of technical writing if they could only find it in print. It is The Logic of Modern Physics by the Nobel Prize Winner, Percy W. Bridgman (Reference 1). It was originally published by Macmillan in 1927 and re-issued in paperback in 1961.

But now, having defined the terms, or the phenomena, the scientist seeks to predict relationships between them. "Reynolds number," for example, is a dimensionless number--which simply means a ratio, like pi--which is the result of combining the viscosity, or stickiness, of an incompressible fluid, like oil or water, with the velocity of its flow and the length of the pipe in which it flows. For some curious reason if the Reynolds number is below 1000, the flow is smooth, or laminar. Beyond that number it starts to become turbulent, until at 100,000 it is definitely turbulent. This is very important for aerospace engineers and mechanical engineers to know. Mechanical engineers want turbulent flow in the cylinders of your automobile engine so that the gasoline and air will mix thoroughly. Aerospace engineers are usually trying to avoid turbulent flow because it creates drag and slows down the

aircraft.

It is through experiment that scientists establish these relationships, and it is important for the teacher of technical writing to have an idea of the rhetorical logic behind an experiment. It is interesting to note that the overall plan of an experiment is the same in every science.

What is this plan?

One naturally begins with a sequence of puzzling events which he would like to explain to himself--explain in the sense of being able to predict when, and under what conditions, these events will occur in this sequence. If one can do this, one may be able to modify, or control, the conditions and thus make the events occur or not occur as one wishes.

For example, the German entomologist, Karl Von Frisch, was much interested in the behavior of honey bees. He noticed that when he placed a pan of sugar water at some distance from a hive of honey bees, a single bee, a scout, would eventually find the sugar water, sample some, and fly off in the direction of the hive. shortly thereafter a crowd of honey bees would appear at the sugar water pan. It appeared to Von Frisch that the scout bee had in some way told the other bees where the sugar water was located. But how?

The next step in the experimental plan is to isolate some features of this sequence of events that seem to be related in some way.

Von Frisch did this by cutting a hole in the front of the hive in order to see what the scout bee did when he returned to the hive. The first scout bee, clearly identified by blue chalk dust sprayed on it when it settled on the sugar water pan, climbed up the vertical wall of the honey comb frame, and there performed a sort of dance in the form of a figure 8.

Now comes the crucial step in the experimental plan--an act of pure imagination. The experimenter now makes an inspired guess about the relationship between two--only two, if possible--events in this puzzling sequence. This is called the hypothesis, and the mark of a really good scientist is his ability to create simple, clear, and testable hypotheses.

Von Frisch's guess, or hypothesis, was that the bee's figure 8 dance--remember that this is on the vertical wall of the honey comb--was related to the direction--on the horizontal plane--of the pan of sugar water from the hive.

Now some way must be found to test this guess in order to find out if it is a good one or a bad one. If the hypothesis cannot be tested, it is essentially useless.

The first step in the test is to figure out which of the two events, which you guess are related, can be changed or modified. This is called the independent variable.

Since it would be difficult, if not impossible, to reach into the hive to change the figure 8 dance of the bee, Von Frisch naturally chose to change the direction of the pan of sugar water in relation to the hive.

But you need to go further than this. You need to devise some measure of the change you plan to make in the independent variable. That was simple for Von Frisch. Compass directions would do; the pan of sugar water could be North, or zero degrees; East, or 90 degrees; South, or 180 degrees; or West, or 270 degrees from the hive.

Next you must choose which aspect of the related event to observe and record. This is called the dependent variable because you expect it to change depending upon how you change the related independent variable. As you can guess, Von Frisch chose to observe the direction the bee took in crossing the figure 8. And the dependent variable must be measured also. That was simple in this case: straight up, or zero degrees; to the right, 90 degrees; straight down, 180 degrees; and to the left, 270 degrees.

Finally, what do you expect to happen if your guess, or hypothesis, is correct? Naturally you hope that as you move the sugar water by 90 degrees, the bee's dance will rotate by 90 degrees, and if you plot the measure of the independent variable on the horizontal axis of Cartesian coordinates--an ordinary graph--and the measure of the dependent variable on the vertical axis, you will get a nice, neat straight line--a linear relationship.

But hold on a minute! There are all sorts of other things that might cause the bee to change his dance: the amount of sugar water in the pan, the distance of the pan from the hive, and so

forth. You don't want these to influence the bee's dance and change the results you expect. So you do your best to cancel out these other possible causative variables. In this case you can always keep the pan full and always keep it the same distance from the hive no matter what its direction. But no matter how hard you work at this, you will probably find that you have overlooked something. Von Frisch did.

Now you run your test and plot your results. Von Frisch simply moved the sugar water pan by degrees and recorded the degrees of the bee's dance. Sure enough, the bee's dance changed as he had predicted. But not in a nice, neat linear way. Some other overlooked causative variable was also influencing the bee's dance.

I am not going to tell you what it was because I think you should read Von Frisch's account for yourself (Reference 6). It is just as exciting as a good detective story, and by the end of his short little book Von Frisch can make that scout bee tell a lie to the other bees and send them off in the wrong direction.

This same sequence of steps is followed, in general, in experiments in most of the sciences. To make the plan easier to follow, I append an outline and an illustration.

But now the results you obtain on your test must be persuaisvely presented. Can you demonstrate that your results are not accidental, not merely the result of chance? The most persuasive argument you can use here is naturally mathematical because chance and probability are mathematical concepts. That is one of the reasons that scientific manuscripts seem to be full of mathematical and statistical formulas; they are normally arguing against the null hypothesis, the hypothesis that sheer chance or accident could produce the same results that you believe you have created by carefully manipulating your independent variable and measuring the dependent variable.

Such mathematical proofs are not so difficult to understand if you can persuade the scientist to show you what it is he is trying to prove, rather than showing you how he is trying to prove it mathematically. Remember, he is trying to prove that there is

some sort of relationship between observable and measurable physical phenomena. The mathematical symbols he uses are simply substitutes, a form of shorthand, for ordinary English words.

For example, the mathematical formula for a coefficient of correlation is

$$r^2_{xy} = \frac{[N \text{ Sum } XY - (\text{Sum } X)(\text{Sum } Y)]^2}{[N \text{ Sum } X^2 - (\text{Sum } X)^2][N \text{ Sum } Y^2 - (\text{Sum } Y)^2]}$$

What is the world does all this mean? If I explain that N represents the total number of individuals tested, that X is the symbol for a series of individuals' scores on one test, and that Y is the symbol for the same individuals' scores on a second test, you probably could compute a coefficient of correlation. But still, what does it all mean?

The number you get after finding the square root of r^2 simply tells you how close the data points you plotted on your Cartesian coordinates, your graph, are to a straight line. If N was the number of observations you made of those bees, and X represented the position in degrees of the sugar water from the hive for each observation, while Y represented the position in degrees of the bee's dance for the same observation, and the square root of r^2 turned out to be 1.00, you would find the data points all fell on a straight line and you had a perfect correlation. Likewise if r turned out to be 0.00, you would find the data points scattered all over the graph, indicating no correlation, or connection, between the location of the sugar water and the direction of the bee's dance.

Once you can get the scientist to explain to you what physical, measurable phenomenon each symbol in his formula stands for and what the whole formula demonstrates, the mystery of the mathematics starts to evaporate and everything becomes clearer.

However, you may find that some students are taught almost entirely in mathematical language--this is especially true of electrical engineers--and accept the validity of a formula without

understanding what operations led to the creation of the formula. A student may tell you, for example, that Ohm's Law is E = I x R, but he may not know that George Simon Ohm discovered this relationship between electromotive force, E, or voltage, and I, or amperes, and R, or resistance, by simply draping different lengths of wire connected to the terminals of a battery over an ordinary magnetic compass. Ohm discovered that the shorter the wire--thus the smaller the resistance--or the larger the battery--thus the larger the voltage--the more the compass needle was deflected in degrees from North.

So I return to the importance of operational definitions in the rhetoric of scientific writing. Get the scientist, no matter what his field, to tell you, or even better, show you, what he does when he defines phenomena and establishes their relationships and I believe that most scientific writing can be made not only clear but interesting.

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PLAN OF AN EXPERIMENTAL INVESTIGATION

I. Analysis of the Problem

A. Description of the situation

B. Observed events to be accounted for or explained

C. Hypothesis - probable explanation of observed events

(This is the most important part of the whole report and must be very carefully explained.)

II. Feasible tests of hypothesis

A. Procedure for Test #1

1. Method of measuring observed event (dependent variable)

2. Method of measuring probable cause (independent variable)

3. Methods for controlling or cancelling out other possible causes

4. Steps in manipulating probable cause (independent variable)

a. Step #1

b. Step #2

5. Method of analyzing results

6. Results expected if hypothesis is correct

III. Tests actually performed and results

A. Test #1

1. Actual procedure

2. Actual results

B. Test #2

IV. Conclusions

ILLUSTRATION OF AN EXPERIMENTAL PLAN

From Karl von Frisch, Bees

I. Analysis of problem

A. A scout bee, having located honey, returns to the hive and performs a dance, in the form of a figure 8, on the vertical wall of the hive. This seems to tell the other bees, who crowd around, the location of the honey.

B. Bees coming in from different directions seem to point the crossing of the 8 in different directions.

C. Hypothesis - I will guess that the direction of the crossing of the 8 is directly related to the direction of the honey from the hive.

II. Test of hypothesis

A. Procedure for Test #1

1. I will measure the direction of the crossing of the 8 in angles clockwise from the vertical.

2. I will measure the position of the honey pot in angles clockwise from the door of the hive.

3. I will keep the honey pot always the same distance from the hive. The same amount of honey will always be used. Several bees will be observed each time to cancel out individual differences among bees.

4. Steps in manipulation of independent variable

a. Set honey pot 1500 meters directly in front of hive.

b. Set honey pot at 90 degrees to right.

c. Set honey pot at 180 degrees.

d. Set honey pot at 270 degrees.

5. I will plot the angle of the bee's dance against the angle of the pot from the hive.

(Over)

6. If the hypothesis is correct, the direction of the dance should change 90 degrees with each change of position of the honey pot.

B. Procedure for Test #2 -- non-existent.

III. Tests actually performed and results

A. Test #1

1. Procedure

8:00 AM - Honey pot directly in front of hive equivalent to 0° or 12 on a clock face

9:00 AM - Honey pot at 90° equivalent to 3 on a clock face

10:00 AM - Honey pot at 180° equivalent to 6 on a clock face

11:00 AM - Honey pot at 270° equivalent to 9 on a clock face

2. Results

8:10 AM - Bee's dance points up, equivalent to 12 on a clock face

9:10 AM - Bee's dance points 45° to right, equivalent to about 2 on a clock face

10:00 AM - Bee's dance points 120° to right, equivalent to about 4 on a clock face

11:00 AM - Bee's dance points down about 200°, equivalent to about 7 on a clock face

The bee's dance follows the location of the honey pot but lags behind. This is <u>not</u> a linear relationship.

IV. Conclusions - Hypothesis is not proved, but is pretty close. Some other variable, perhaps time of day, seems to be involved. Another hypothesis must be devised.

ILLUSTRATION OF STUDENT EXPERIMENT

Tool Life and Side-Rake Angle

1. Situation

Metal cutting operations are costly. In turning operations on a lathe the grinding of tool bits to the proper angles has normally been left up to the individual machinist who chose the angles based upon his own experience, rather than upon experimentally determined evidence. For this reason the life of tool bits used in the same operation has varied markedly from machinist to machinist.

This test will be performed to determine the optimum number of degrees for just one angle--the side-rake angle--on a tool bit used in a metal cutting lathe.

Hypothesis - The life of a tool bit changes with the side-rake of the tool bit, other things being equal.

2. Test of Hypothesis

a. Dependent variable - tool life.

Tool life may be measured as the number of minutes after the start of the turning operation when any of the following occur: (1) the tool bit starts to glow red hot, (2) the surface finish of the metal being cut starts to deteriorate, (3) a grating or chirping noise occurs, or (4) the tool bit stops cutting.

b. Independent variable - side-rake angle.

Side-rake angles will be ground to 0°, 20°, 30°, and 45° as measured on the tool grinding wheel.

(Over)

c. Other possible causative variables to be kept constant.

1) 340 stainless steel work material will be used for all tests.

2) M-2 high-speed steel tool bits will be used for all tests.

3) All tool bits will have 0° back-rake angle.

4) " " " " " 6° end-relief angle.

5) " " " " " 7° side-relief angle.

6) " " " " " 6° end cutting-edge angle.

7) " " " " " 0° side cutting-edge angle.

8) " " " " " 0.0 inch nose radius

9) The depth of cut on all tests will be 0.050 inches.

d. Test procedure.

Eighteen (18) tests will be performed for each tool bit side-rake angle. Three different feed-rates and six different rotational velocities will be used as follows:

Feed-rate in inches per revolution	Rotational velocity in feet per min.
0.002	140 150 160 170 180 200
0.006	140 150 160 170 180 200
0.012	140 150 160 170 180 200

Minutes of tool life for each side-rake angle will be recorded during each test.

e. Method of analyzing results.

For each side-rake angle and feed-rate, the minutes of tool life versus the rotational velocity will be plotted on logarithmic graph paper.

f. Results expected if hypothesis in question is answered yes.

It is expected that the data points will fall on a straight line. The slope of this line should enable one to predict tool life, given the side-rake angle, the feed-rate, and the rotational velocity.